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Professor Luhmann, Jr

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University of California, Davis
410 Mrak Hall
Davis CA 95616-8671

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13. ABSTRACT *(Maximum 200 words)*

In this AASERT project, basic studies were performed to provide the understanding for higher performance gyroklystrons and an attempt was made to improve the performance of Varian/CPI's pioneering gyroklystron amplifier, which encountered significant oscillation problems.

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COLLEGE OF ENGINEERING
DEPARTMENT OF APPLIED SCIENCE DAVIS-LIVERMORE

ONE SHIELDS AVENUE
DAVIS, CALIFORNIA 95616

April 25, 2000

Dr. Robert Barker
Program Director
Directorate of Physics and Electronics
AFOSR/NE
801 Randolph St. Room 732
Arlington, VA 22203-1977

Dear Dr. Barker,

Please find a copy of our Final Technical Report, for our AASERT Grant entitled "High Performance Gyroklystron Amplifier," Grant No. F49620-95-1-0458, for the period 7/1/95-6/30/99.

Sincerely,

L. Tobado for

N.C. Luhmann, Jr.
Professor, Applied Science
Professor, Electrical and Computer Engineering

Enclosures

Cc: Fay Yee, OVCR

AFOSR AASERT Grant F49620-95-1-0458
PI: Professor N.C. Luhmann, Jr., UC Davis, Department of Applied Science
Final Progress Report. Grant Period: 7/1/95 - 6/30/99 Report Date: 4/24/00

High Performance Gyroklystron Amplifier

1. Publications and Conference Proceedings during Period--7/1/95-6/30/99

J.D. McNally, D.B. McDermott and N.C. Luhmann, Jr., "Third-Harmonic TE_{411} Gyroklystron Amplifier," *IEEE Trans. on Plasma Science*, vol. 26, no. 3, pp. 496-499, 1998.

J.D. McNally, D.B. McDermott, and N.C. Luhmann, Jr., "UCD Gyroklystron Program," *Bull. Am. Phys. Soc.* 40, 1675, 1995.

J.D. McNally, D.B. McDermott, and N.C. Luhmann, Jr., "UCD Harmonic Gyrotron and Gyroklystron Program," Abstracts for 1996 Microwave Power Tube Conference, 2E.27, 1996.

J.D. McNally, D.B. McDermott, and N.C. Luhmann, Jr., "UCD Gyroklystron Amplifier Program" *Abstracts of Microwave Vacuum Electron Device Conf.*, paper 2E.8, 1998.

2. Overview

Fast-wave devices have exceeded by orders of magnitude the power levels of slow-wave millimeter-wave devices. CW gyrotrons now generate 110 GHz at megawatt power levels. Gyroklystrons offer the high power capability of gyrotrons and are appropriate for DoD's next-generation radar and communications applications. In a recent collaboration between the national laboratories, industry, and universities, a high performance, 94 GHz gyroklystron was developed that produced an average power of 10 kW. In this AASERT project, basic studies were performed to provide the understanding for higher performance gyroklystrons and an attempt was made to improve the performance of Varian/CPI's pioneering gyroklystron amplifier, which encountered significant oscillation problems. A high power, CW relevant, fundamental frequency, three-cavity 33 GHz gyroklystron employing the low loss TE_{0n} modes was designed with a state-of-the-art simulation code for 250 kW, 39% efficiency and 52 dB gain and then built. Potential applications of this device include synchronous satellite communications and deep-space radar for DOD. An experiment was performed.

In addition, the concept that harmonic gyrotron amplifiers are capable of generating much higher levels of power, which has been verified for gyro-TWT's by the PI's experimental group, has been extended to gyroklystrons for the design of a high power third-harmonic gyroklystron amplifier. Harmonic gyro-amplifiers can generate significantly higher power because the start-oscillation current is much higher due to the relatively weaker harmonic interaction. A key to the

design is the mode selective circuit that suppresses competing modes by interrupting their wall currents.

3. Fundamental Harmonic Gyroklystron

A high performance 80 kV, 8 A, cw-capable gyroklystron has been designed using a self-consistent gyroklystron simulation code and the device has been built. The objective of the experiment was to upgrade Varian's 1977 gyroklystron experiment which encountered stability problems. The UCD three-cavity, TE_{0n} gyroklystron is summarized in Table I. Its predicted performance shown in Fig. 1 is 250 kW saturated output power with 50 dB gain and 40% efficiency. The amplifier uses a donated Varian MIG and a superconducting magnet donated by Hughes Aircraft EDD. The gyroklystron was fabricated and Fig. 2 shows the primary components of the circuit. The assembled circuit is shown in Fig. 3. The three cavities were each tuned to 33.14 GHz with adequate loading and coupling (see Fig. 4). A lossy drift tube was built to suppress the oscillations observed in the 1977 tests. The amplifier was placed in the bore of the solenoid and pumped down to 10^{-7} T. The MIG was successfully re-activated. A 10 W CW, 26-40 GHz TWT amplifier was used as the input for the test amplifier. In the initial hot tests, appreciable levels of oscillation were observed. By reducing the electron beam's $v_{\perp}/v_z$ to less than 1.0, the gyroklystron was stabilized. However, the gain could then not be increased above 0 dB. It was discovered that the middle cavity had somehow become desynchronized so that the gyroklstron was performing like a two-cavity device. The poor gain could be explained by the overly long length of the drift tube for a two-cavity device.

4. Third Harmonic Gyroklystrons

We have also designed two innovative high power smooth-bore three-cavity gyroklystrons that are based on the concept that harmonic operation can lead to stable amplification at extremely high power levels. These third-harmonic gyrokystrons display performance characteristics comparable to first-harmonic gyroklystrons. The feature of these devices is that operation at the third cyclotron harmonic allows the magnetic field to be reduced by a factor of three. The 4.5 kG magnetic field needed by a 35 GHz amplifier could thereby be produced by a lightweight rare-earth permanent magnet, while the 12.4 kG field for a 95 GHz device could be generated by a copper coil electromagnet. They are summarized in Table II. One of the third-harmonic gyroklystrons employs an axis-encircling electron beam produced by a Cusp gun and the other uses a more common annular electron beam produced by a MIG gun. Both amplifiers are predicted to produce 70 kW with 20% efficiency and 30 dB saturated gain. They are predicted to have identical amplifier characteristics, as shown in Fig. 5, except that the gyroklystron with a Cusp gun has a broader bandwidth, as shown in Fig. 6. This is because they were both designed to have the same value of interaction coupling coefficient times cavity Q_L. The cavity Q of the MIG design was increased from the Cusp design to compensate for the weaker interaction. However, to maintain the amplifiers' stability from lower harmonic interactions, the gyroklystron circuits must also be sliced to destroy modes without the operating modes' azimuthal symmetry. Tests of these smooth-bore devices are planned to determine

whether a more robust smooth-bore circuit can yield superior characteristics for harmonic operation compared to slotted circuits. These smooth-bore devices allow greater beam separation from the cavity walls and lower rf electric field densities than in the slotted magnetron-type cavities that were considered by industry in the recent 95 GHz, fast-wave amplifier ARPA program.

Table I Design parameters of the 33 GHz TE_{0n} gyroklystron.

Beam Voltage	80 kV
Beam Current	8 A
$v_\perp/v_z$	1.5
Frequency	33.1 GHz
Magnetic Field	12.4 kG
Mode (1,2,3)	TE_{011}, TE_{011}, TE_{021}
Cavity Q (1,2,3)	300, 300, 550
Cyclotron harmonic	First
Cavity radius	5.69 mm
Cavity length	1.81 cm
Drift tube lengths	2.71 cm
$\Delta v_z/v_z$	7%

Table II Design parameters for the 95 GHz three-cavity, third-harmonic (a) TE_{311} and (b) TE_{411} gyroklystron amplifiers.

Beam Voltage	70 kV	70 kV
Beam Current	5 A	5 A
α ($v_\perp/v_\parallel$)	2.0	2.0
Guiding Center Radius	0.0	0.5 r_w
Frequency	95 GHz	95 GHz
Magnetic Field	12.4 kG	12.4 kG
Mode	TE_{311}	TE_{411}
Cyclotron Harmonic	3rd	3rd
Cavity Radii, r_w	0.21 cm	0.27 cm
Cavity Lengths	1.27 cm	1.27 cm
Drift Tube Lengths	0.63 cm	0.63 cm
Cavity Q's	225	1300
$\Delta v_z/v_z$	10%	10%

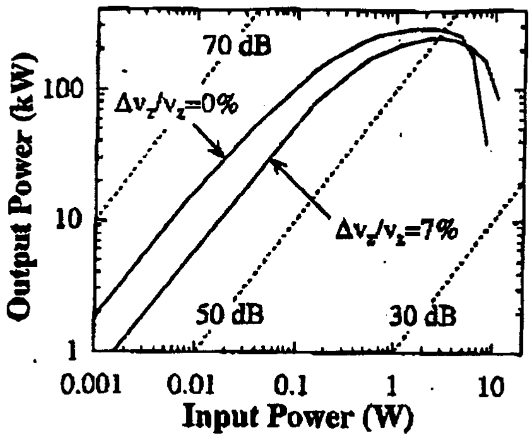

Fig. 1. Predicted transfer curve for UCD TE_{0n} three-cavity gyroklystron amplifier (Table I).

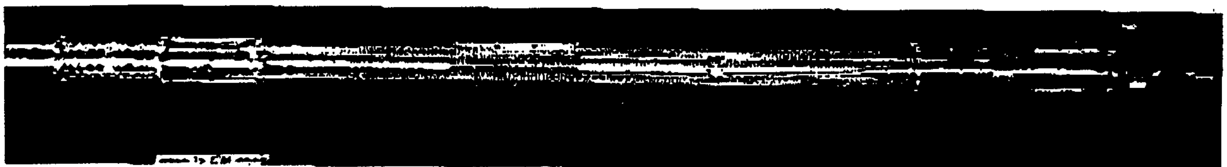

Fig. 2. Photograph of the assembled UCD TE_{0n} gyroklystron. The cavity circuit is located roughly one-fifth of the total length from the left. The collector's permanent magnet stack is located two-fifths from the left.

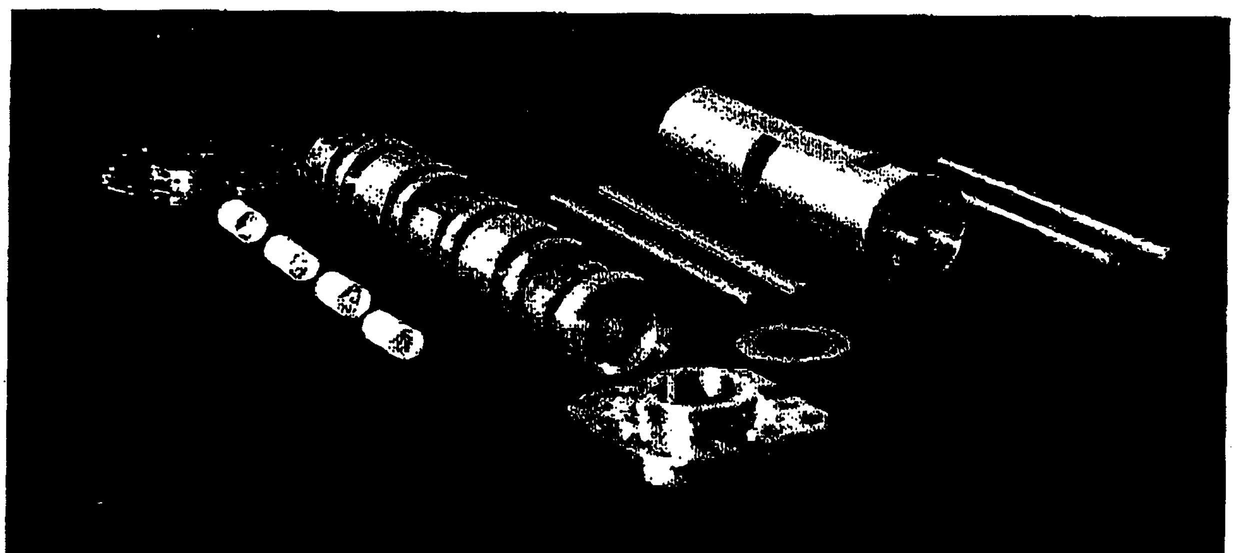

Fig. 3. Photograph of the disassembled components for the UCD TE_{0n} gyroklystron circuit. Clockwise from the upper left, the six groups are: 1) the dielectric rings to load the cavities and drift-tubes; 2) the cavities and drift-tubes; 3) two alignment posts; 4) the circuit enclosure; 5) two more alignment posts; and 6) the base for the circuit.

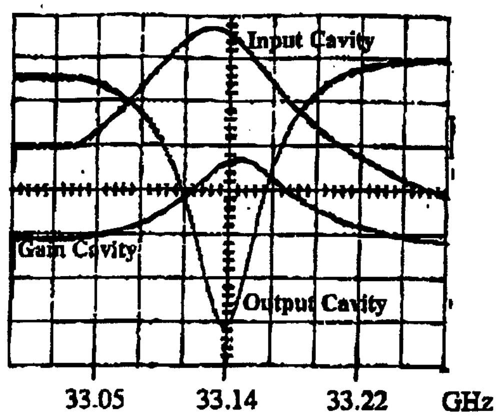

Fig. 4. Measured frequency response of the three cavities in cold tests of the UCD TE_{0n} gyroklystron amplifier.

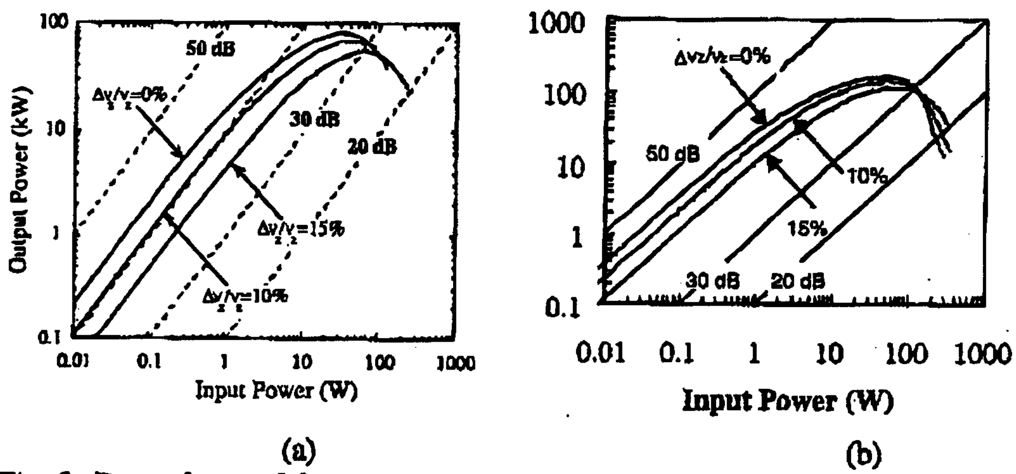

Fig. 5. Dependence of the output power on input power for the 95 GHz three-cavity third-harmonic (a) TE_{31} and (b) TE_{41} gyroklystron amplifiers for several values of velocity spread.

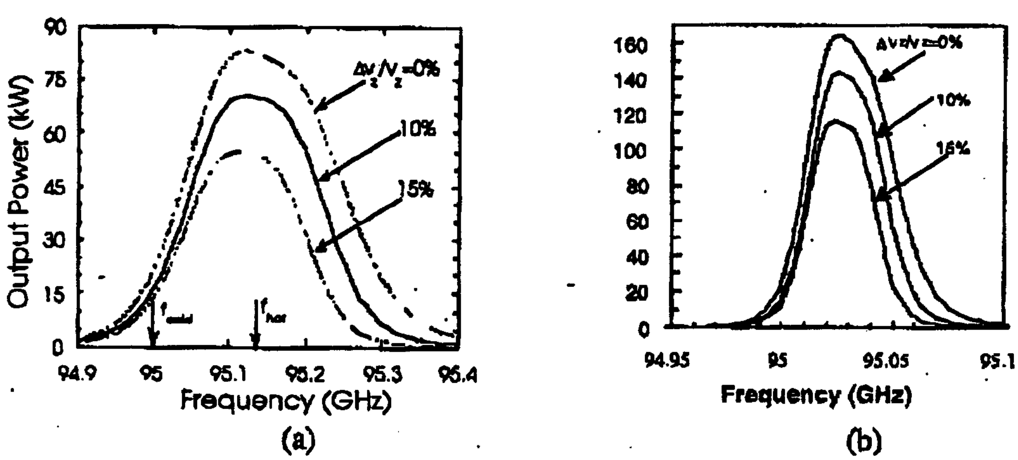

Fig. 6. Bandwidth of the 95 GHz three-cavity third-harmonic (a) TE_{31} and (b) TE_{41} gyroklystron amplifiers for several values of velocity spread.

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ffyee@ucdavis.edu
cgwilm@ucdavis.edu
OFFICE OF THE VICE CHANCELLOR FOR RESEARCH
(916) 752-2075
FAX: (916) 752-5432

410 Mrak Hall, One Shields Avenue
DAVIS, CALIFORNIA 95616-8671

Lori Chabricky
Contract Administrator
AFOSR/JA
110 Duncan Avenue Room 114
Bolling AFB DC 20332-8050

MAY 6 1998

Dear Ms. Chabricky:

Grant No. F49620-95-1-0458
Principal Investigator - Neville C. Luhmann, Jr.

As allowed under the provisions of the Federal Demonstration Project, an extension without additional funds has been approved by our institutional representative for the subject grant. The existing **June 30, 1998** expiration date has been extended to **June 30, 1999.** This extension was authorized in order to assure adequate completion of the original scope of work within the funds already made available. Please change your records accordingly.

Thank you for your cooperation. Should there be questions, please direct them to me by telephone or facsimile at the above referenced numbers.

Sincerely,

Fay Yee
Contracts & Grants Analyst

c: N.C. Luhmann
G. Max
R.J. Barker